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SURVEY OF MARITIME EXPERIENCES IN REDUCED WORKLOAD AND STAFFING

FINAL REPORT
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16. Abstract (MAXIMUM 200 WORDS)

The U.S. Coast Guard is in the Concept Exploration Phase of its Integrated Deepwater System (IDS) acquisition. This project will define the next generation of surface, air and command, control, communications, computers, intelligence, sensors, and reconnaissance (C4ISR) assets used to perform the Coast Guard's missions in the Deepwater environment (>50 NM off the U.S. coastline). A ship's crew represents a major life-cycle cost of operating and maintaining a USCG ship. Reducing shipboard work requires an understanding of the mission and support requirements placed on the ship and its crew; how these requirements are currently met; and how requirements might otherwise be met to reduce workload and crew size.

The objective of this effort was to support the development of an optimized crewing strategy for the surface platform of the IDS by surveying work-reducing approaches of other maritime fleets (foreign coast guards and navies, and commercial fleets). From the data collected, strategies for shipboard work reduction that may be considered for adoption by the Deepwater Project were identified and analyzed according to performance and costs factors. Each strategy developed during the effort was based on the approaches and techniques observed by the maritime organizations surveyed.

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Executive Summary

The U.S. Coast Guard (USCG) is in the Concept Exploration Phase of its Deepwater Capabilities Replacement Project. This project will define the next generation of surface, air and command, control, communications, computers, intelligence, sensors, and reconnaissance (C4ISR) assets used to perform the Coast Guard's missions in the Deepwater environment (>50 NM off the U.S. coastline). A ship's crew represents a major life-cycle cost of operating and maintaining a USCG ship. To reduce shipboard work requires an understanding of the mission and support requirements placed on the ship and its crew; how these requirements are currently met; and how requirements might otherwise be met to reduce workload and crew size. As part of early technology investigations, the need exists to (1) analyze the workload requirements of the Deepwater system, (2) identify means to control the amount of work performed aboard Deepwater Cutters, and (3) to optimize ship manning in accordance with the extent of ship's work and mariner work productivity. In view of these needs, the overall objective of this effort was to support the development of an optimized crewing strategy for the Coast Guard's Integrated Deepwater System (IDS) by surveying work-reducing approaches of other maritime fleets.

The approach followed in this project was to examine currently implemented workload and manpower-reducing strategies of commercial maritime fleets, U.S. and foreign navies, and foreign coast guards. Existing crew reduction efforts were surveyed and assessed according to:

- Strategies employed to reduce workload
- Effects of those strategies on mission effectiveness and safety
- Effects of technology and automation on work reduction
- Costs of implementation
- Life-cycle costs implications of reduced work/crew platforms, and
- Implications of crew reduction techniques on human and system performance.

From these data, strategies for shipboard work reduction that may be considered for adoption by the Deepwater Project were identified and analyzed according to performance and costs factors. Strategies can reduce crew by: (1) reduction of *workload* via application of automation, or (2) task and procedure redesign.

Ten workload reducing strategies were generated, as follows:

- Damage Control Strategy
- Multiple Crewing Strategy
- Risk Acceptance Strategy
- Deck Strategy
- Ship / Personnel Readiness Strategy
- Bridge Strategy
- Engineering Strategy
- Modularity Strategy
- Use of Enabling Technologies
- Design for Operability and Maintainability

This report does not advocate the adoption of any strategy. Rather, what is reported is simply what other fleets have tried, and what may be: (1) considered by the USCG for possible acceptance within the IDS, (2) selected for further review and analysis, or (3) rejected.

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1.0 INTRODUCTION

1.1 Background

The overall objective of this effort was to support the development of an optimized crewing strategy for the Integrated Deepwater System (IDS). Optimized crewing is the minimum crew level for a ship consistent with human performance and safety requirements, available technology, affordability and risk. Optimized crewing also encompasses optimized crew performance, workload, and safety. Optimized crew performance means that each crew member, acting alone or in a team, will be capable of performing all tasks as required, to the required accuracy and throughput, and within time constraints, in all expected mission conditions. Optimizing performance requires Human-System Interfaces (HSI) to be designed to facilitate human performance and paying close attention to the detailed Human Factors Engineering (HFE) aspect of HSI design. Optimized workload refers to the level of sustained workload that will not lead to human errors, either through fatigue or boredom. Optimized safety means zero accidents.

The basic approach of this effort was to: examine already implemented workload and manpower-reducing efforts of maritime fleets (commercial fleets, the US Navy and Coast Guard, and foreign navies and coast guards); assess their success at workload and crew reduction, and; identify potential approaches that may be adopted by the IDS. Existing crew reduction efforts were assessed according to:

- Strategies employed to reduce workload and crew
- Effects of those strategies on mission effectiveness and safety
- Costs of implementation
- Life-cycle costs of reduced crew platforms
- Applicability to the IDS
- Implications of crew reduction techniques on human and system performance

The effort was comprised of four tasks, as follows:

- <u>Conduct Literature Search</u>. The objective of this task was to perform a literature survey addressing ship crewing. The search covered government and merchant fleet acquisition programs worldwide.
- <u>Develop Survey Plan</u>. The objective of this task was to publish a survey plan designed to: specify the means by which surveys were performed; determine how information collected was to be analyzed; identify how alternate manpower reduction strategies for the IDS were to be developed, and; identify means to estimate the level of workload/crew reduction that may be realized for each strategy, if adopted and implemented by the IDS.
- <u>Perform Survey of Successful Manpower Reduction Programs</u>. The objective of this task was to implement the plan generated in Task B and identify specific characteristics, approaches, and lessons learned from successful crew reduction programs. Successful programs were originally defined as those that resulted in manpower reductions of at least 15% and that had a minimum of a three year history of implementation in working fleets.
- <u>Identify the Impacts of Staffing and Maintenance Strategies on Life-Cycle Costs</u>. The objective of this task was to identify the impact on life-cycle cost of the crew and maintenance strategies identified by the Coast Guard as being viable for the Deepwater Surface Platform.

1.2 Issues

Reducing workload on ships at sea typically involves three components:

- Application of automation technology
- Modification of operational and maintenance procedures and protocols
- Imposition of new knowledge, skill and abilities (KSAs) on the crew, which in turn can impose new training requirements.

In addition, as part of the design process, tradeoffs are made that significantly influences the ship and it's performance. These represent issues that must be addressed in the design of reduced workload and crew for the surface platform of the IDS. In the surveys, these encompassed factors such as:

- Cost Factors
  - R&D
  - Acquisition and implementation
  - Logistics and life cycle support
- Operations and Support
- Personnel Factors
  - Readiness
  - Fatigue
  - Training
- Performance Factors
  - Operational changes
  - Shore infrastructure
  - Readiness
  - Reliability
  - Maintainability
  - Safety

1.3 Objectives of the Survey Plan

The objectives of the survey plan were to:

- Develop the tools and a schedule for conducting surveys of maritime organizations that have established workload and crew reductions for ships at sea
- Apply the surveys at a total ship and ship function level
- Assess the information in the context of a matrix of functional areas by issues
- Identify concepts for crew reduction that are applicable to the surface platform of the IDS
- Database the information in a form such that a tool can be used to support the cost assessment and tradeoff process in the design of the surface platform of the IDS .

The survey instrument addressed manpower and workload reduction that has been achieved for overall ship crew, and for crew/workload reduction in specific ship functional areas. These specific functions areas are presented in Table 1.

Table 1. Functional Areas for Reduced Workload Surveys	
Mission Operations	**Special Operations**
Boat Handling/Boarding	Underway Replenishment
Area Surveillance	Electrical Failure
Communications - Internal	Extreme Weather
Communications - External	Fire - Large and Small
Weapon and /Combat Information	Flooding/Ballast control
Helicopter/UAVs	Collision/ Grounding/ Stranding
NOAA/Weather services	Internal Security
Oceanographic	Loss of Propulsion
SAR	Search and Rescue
Deck Operations	Boarding/Law Enforcement
Anchoring	Anti-Terrorism
Docking Undocking	Man Overboard/Rafters
Helo Operations	Fuel Spills/Environment Hazards
Boat operations	Lifeboat
Line Handling/Mooring	**General Operations**
Anchor	Bridge - Housekeeping
Towing Operations	Bunkering
Underwater Lighting	Deck Equip Maintenance
Navigation/Bridge	Direct Shore Gangs
Approach Berth	Docking/Undocking
Berthing	Line/wire Maintenance
Collision Avoidance	Medical
Depart Berth	Stores Breakdown
Hull Performance/Station Keeping	Steering Gear Maintenance
Maintenance	Stores Handling/Breakdown
Maneuver	Structure Maintenance
Lookouts	Wash down - Deck and Engineering
Signals	**Administration**
Position Fixing	Reporting
Record/chart Keeping	Health Care
Track Keeping	Ships Meetings
Voyage Planning	Finance/Payroll
Weather Monitoring	Mission Planning

Table 1. Functional Areas for Reduced Workload Surveys (continued)	
Hotel/Unit Support	**Shore Operations**
Catering/Messing	Stores loading
Laundry	Port Logs/Records
Provisioning	**Maintenance - Ship area**
Space Cleaning	Vital Systems Test
Waste Disposal	Equipment Surveillance
Maintenance - Overview	Computers
Maintenance Philosophy	Electric System
Depot/Shoreside	Evaporators
Intermediate	Fuel Oil
Hull	Fuel Transfer
Unit	Generators
Training and Personnel Support	Inert Gas
Off ship and Schools	Propulsion
OJT	Pumps/Valves
Cross training	Tools/Test Equipment
Engine and Auxiliaries Operations	Communications
Record Keeping	Boat Maintenance
Routine Operations	HVAC
Watch Standing	Housekeeping (common and rec areas)

2.0 SURVEY METHOD/APPROACH

The approach followed is described below and is summarized in Figure 1.

2.1 Survey Activities

The survey consisted of two parts. The first established an overview of the missions, operations and maintenance characteristics of the ship(s) with reduced workload and crew. It was intended to capture the typical elements of life-at-sea aboard the ship under review. The first portion of the survey required about one hour to complete and addressed:

- Total ship crew size
- Overall crewing/crewing philosophy
- Mission
- Watch Standing and Duty Stations
- Normal and special operations and evolutions
- Support functions
- Maintenance (unit, intermediate, depot)
- Training (on board)
- Applications of automation
- Emerging technologies
- Environments

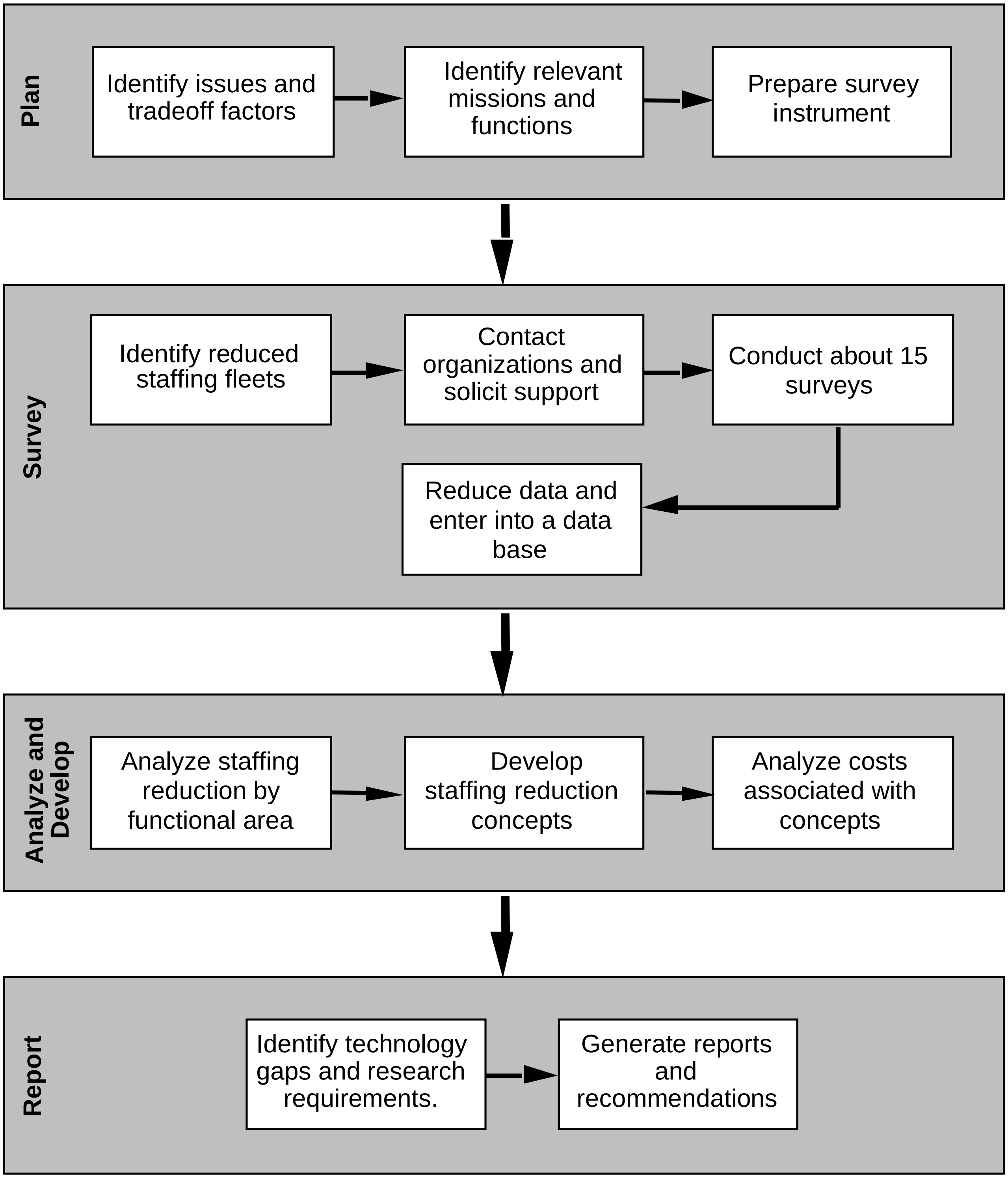

Figure 1. Survey Task Process

The second part of the survey addressed strategies associated with reducing functional workload (Table 1). Each function of Table 1 was discussed with survey participants to solicit their comments related to:

- Organizational experience related to the function and work reduction, including safety, cost, system performance and effectiveness.
- Work-reducing technologies or approaches, addressing what has been tried in order to reduce workload, including application of automation, reallocation of functions, and redesign of procedures and policies.
- Evidence of success or failure of approaches, and methods/metrics by which success or failure has been assessed. Soft measures (such as "crew morale"), as well as hard measures (such as cost and direct measures of workload) were solicited.
- Costs associated with reducing workload or manpower, including RDT&E costs, acquisition costs, and support cost data were solicited.

2.2 Participation

Government. A cognizant spokesperson from the USCG was required to:

- Provide support-gaining cooperation from management of reduced manned fleets (commercial or military), particularly in soliciting commercial or other sensitive information (related to cost, proprietary designs, and security classifications).
- Make formal requests for participation of reduced crew ship organizations.
- Provide liaison among the contractors, the USCG and representatives of reduced crew fleets (foreign and domestic, military and commercial).
- Participate in the conduct of all surveys in order to: preserve project memory; support real-time issue resolution, and; support evaluation of reduced crew concepts that result from the information attained in the interviews.

Contractor. Contractors were responsible to:

- Generate the survey plan.
- Identify potential survey participant.
- Provide direct support in collecting reduced crew information.
- Collect and maintain the data.
- Maintain contract files.
- Analyze the survey data.
- Develop crew reduction strategies/concepts for the IDS.
- Identify cost factors associated with each concept.
- Assess life-cycle cost impacts for the IDS for each concept.

2.3 Sources of Information

Twelve organizations with an established history of ship operation with a reduced workload and crew size participated. Each organization was contacted and requests were made to secure and schedule participation in this survey. Criteria for selecting potential candidates initially were:

- Must have operated ships with a crew reduction of at least 15%

- Must have a minimum of three years operating experience with a reduced crew size.

These criteria were amended as it became clear that many fleets surveyed use crew sizes that are significantly fewer than is typical of the U.S. Coast Guard, and that those fleets did not experience a manning reduction of 15%. Therefore, it was decided that the criteria would require that reduced crew ships have operated ships with a crew reduction of at least 15% compared to ships of similar size and mission requirements of a comparable Coast Guard cutter. In two cases, the criterion requiring three years experience was not adhered to. The ships in this case were the SmartShip of the USN, and the Coast Guard Cutter DEPENDABLE. These two ships were included because their missions are comparable to the missions of the National Security Cutter of the IDS, they provided proof of concept for very new technology and procedural approaches to reduce work, and they provided a good source of cost data.

Interviews were conducted via telephone or in face-to-face interviews aboard ship. In each session, the following types of personnel were requested to be present:

- Shore support or management - this included commercial operators/agents or base support personnel for military ships.
- Ship management - this includes a reduced crew ship officer (military) or Master/Mate (commercial).
- Working crew - Chiefs or Petty Officers for military vessels, or licensed mariners for commercial ships.

In all interviews, either a shore management representative or a ship manager was present to support the interview. Surveys were not completed using working crew only.

Protocol for Soliciting Participation. The protocol for soliciting participation was as follows:

- Identify candidate organizations for participation:
- from literature review where efforts to reduce ship workload were identified
- via analysis of ship data (Length overall and displacement divided by crew size was used as a metric of reduced manning. See Appendix B for a summary). Selected ship types generally had ratios smaller than operational USCG ships.
- Identify, in each organization, cognizant personnel as initial Points-of-Contact.
- USCG representatives made initial contact:
  - Introduction, stated nature of request for participation and summarized study objectives.
  - Guaranteed information privacy if requested. Offered to share information gathered.
  - Provided USCG points-of-contact for verification of request and identification of contract personnel.
  - Stated information required/requested of participant.
  - Stated that interviews were to be recorded (unless the participant objected).
  - Estimated support required by participants (personnel needed, for how long, and when and where needed).
  - Promise information package to be forwarded to participants detailing contents of the surveys.
  - Get agreement from organizations management to participate.
- Persons conducting the interviews followed up by telephone, arranging schedules, meeting places, and related details of participation.

Protocol for Conduct of Survey/Interviews. With the exception of the information collected from the French Navy, the Japanese Coast Guard, and the Royal Netherlands Navy, all interviews were recorded. Data was collected using the forms contained in Appendix A.

The procedure for conducting the interviews was as follows:

1. Initiated conference call at agreed upon time. Participants were:
   - USCG representative who initiated all calls
   - Contractor personnel who conducted the interviews and who documented the data
   - Representatives of the participating organization
2. Made introductions
3. Verified that the right people are attending
   - Contractor: data analyst, data entry clerk
   - USCG team leader
   - Participant: management representative, ship management (officer or mate), and crewmember (optional)
4. Summarized objectives, schedules, and information requirements.
5. Set up and verified recording equipment working.
6. Began with the overview survey (about one hour)
7. Completed the detailed survey (about one hour)
8. Once done, verified that surveys were complete
9. Identified and documented open items or action items (what - who - when).
10. Arranged for follow-up conversations as needed.

2.4 Data Analysis and Concept Development

The surveys were targeted at identifying manpower-reducing techniques that have been applied in ship design and that have a history of ship operational use. Total ship crew reduction results from:

- workload reductions at the level of the function (automation and procedures),
- integration and synthesis of new functional requirements with new allocations to existing crew members (deriving total crewing),
- development of total ship procedures, protocols and doctrine, and
- new training and certifications of those new crew member allocations.

A total ship crew concept of operations was not developed as part of this effort, however, a notional crew was generated to support cost comparisons of each strategy.

The reduced crew concepts developed in this task address alternatives at the functional or departmental level, e.g., crew concepts for bridge, engineering and auxiliaries, deck, and for special evolutions such as damage control.

Strategies were developed according to the following steps:

Step 1 For each functional area, identify common approaches and experiences.

Step 2 For each functional area, identify recurrent themes.

Step 3 Identify any conflicting approaches (for example, automating a function and eliminating a function).

Step 4 Identify actual or estimated workload or crew reductions for each work-reducing technique.

Step 5 Express workload reduction techniques as logical strategies.

Step 6 Package each strategy into:

- A crewing or workload reduction (for example, in a bridge strategy, identify watch stations, rotations, types of personnel required, numbers required)
- General procedures of operations or applications of technology
- Personnel Implications
- Special cost factors that may have been identified (maintenance, shore support, implementation)

Ten workload-reducing strategies were generated:

- Damage Control Strategy
- Multiple Crews
- Risk Acceptance
- Deck Strategy
- Ship / Personnel Readiness
- Bridge Strategy
- Engineering Strategy
- Modularity
- Enabling Technologies
- Design for Operability and Maintainability

Each of these is discussed in greater detail in section 3.2.

2.5 Cost Analysis Approach

The crewing and maintenance strategies identified by the Coast Guard as being viable for the Deepwater Surface Platform were analyzed for life-cycle cost impacts. For each selected strategy, the cost analysis considered:

- change in number of assigned crew.
- change in number of shore support personnel.
- acquisition, maintenance, and training costs of applicable automation technology.
- maintenance cost impacts of the selected strategy.
- costs of developing and implementing the strategy.

The crewing strategy survey identified the crew reductions achieved and costs of implementing and operating the strategies. Government-furnished standard Coast Guard personnel cost data for both afloat and ashore were used to quantify the personnel cost impact of the selected strategies. The personnel impacts (reductions and increases) were combined with the acquisition and implementation costs of the strategies to determine the life-cycle cost impacts.

Cost estimation tools used were (1) U.S. Coast Guard’s Project Analysis & Cost Estimation (PACE) and (2) the United States Navy Center for Cost Analysis’ Cost of Manpower Estimating Tool (COMET) model.

PACE was the primary cost-modeling tool used. PACE handles a variety of one time costs, annual recurring costs and periodic costs to automatically calculate total costs for alternative approaches. USCG standard personnel costs are imbedded in the model along with default values for general detail, discount rates, etc. The model is structured so that a model will consist of a baseline reference crew and a number of alternatives, each with their associated costs and assigned personnel. PACE compares the alternatives to the reference crew and ranks the alternatives based on costs. The model also includes an environmental ranking feature that was not used for this study. COMET was used to validate and update the USCG personnel cost data contained in the PACE model database.

3.0 SURVEY FINDINGS

3.1 Literature Search

A literature review was performed to help identify experiences of maritime operators with reduced workload technologies and reduced crewing. A full-time librarian with a Masters degree in Library Science performed the literature search. The activities in conducting literature searches were as follows:

- Identify Topic and Search Strategy**:** A candidate list of search keywords was developed with Boolean operators to create meaningful combinations of keywords. Search terms included: Ships ***or*** maritime ***and any of*** reduced crew, reduced workload, reduced manning, automation, manning, manpower, workload, fatigue, accidents.
- Conduct Search: Relevant technical journals, trade magazines, book, and newspapers, were searched.
- Acquire Documents**:** Documents were acquired from commercial database services directly and from on-line sources.
- Abstract Material**:** Documents acquired were reviewed and abstracted by one or more members of the technical staff. The relevant experimental, technical and/or design characteristics identified in each document were highlighted and included in a literature database. This database is presented in Appendix C.

A significant amount of literature was found that addressed the:

- issues associated with reduced workload and crew aboard ships,
- approaches to resolve workload problems, and
- tools for analysis of reduced workload and crew.

Very little was identified that discussed the experiences of specific fleet operators with reduced workload technologies and reduced crewing. This is not surprising, and information of the kind being sought in this effort (fleet experiences with reduced workload and manning) is termed "gray information" within the library sciences. Gray information is that which is unlikely to be in the public domain because of any of the following reasons:

- It is considered to be proprietary to a company or state.
- Efforts leading to the information were based on need and pragmatism, and results of efforts to address needs have not be offered publicly.
- The impetus to reduce work and manpower on ships is relatively new in the United States, and suitable U.S. studies are recently completed or are now being performed.

3.2 Strategies

Each strategy developed during the effort was based on the approaches and techniques observed by the maritime organizations surveyed. This report does not advocate the adoption of any strategy. Rather, what is reported is what other fleets have tried, and what may be (1) considered by the USCG for possible acceptance by the IDS, (2) selected for further review and analysis, or

(3) rejected. Appendix D contains a summary or the work-reducing approaches of each of the organizations included in the study.

From the approaches used in other maritime organizations, workload reducing strategies were identified for the IDS. These strategies:

- Interact and are interdependent, and many assume presence of “enabling” technologies or practices.
- Are conceptual and are very general in their descriptions.
- Were all developed based solely on survey findings.

What is not provided in the descriptions of strategies are:

- Total ship definition/conceptual ship designs.
- An overall manning organization.
- Total ship watchstations and station bill.
- Specific roles and responsibilities of individual crew.
- Needed legal and cultural changes that are required to implement any specific approach.
- An analysis of technological or operational risks.

The strategies developed for the IDS are presented below.

3.2.1 Damage Control (DC) Strategy.

A reduced crew makes fire fighting difficult and timely response to fire onset uncertain. An example of automation technology is a series of point-source fine spray mist fire suppression systems at key points throughout the ship. These systems have been shown to be highly effective in putting out petroleum based fires. Points where these systems should be installed include those that offer both the greatest probability of fire and the greatest potential damage. These include: fuel transfer stations, bilges, lube oil cooling and filtering stations, main and auxiliary diesels, paint lockers, and galleys. Dry goods lockers and habitability spaces are also candidates. Thermal and smoke detection systems should be capable of automatically actuating these fire suppression systems during non-day work periods. Some control can be exercised from the bridge via use of closed circuit television (CCTV) to monitor critical spaces and control the fire suppression systems. CCTV is also essential for remote AFFF fire suppression of engine room fires (to make sure the space is clear of people and barriers are closed). A fire control station is needed on the bridge, or other manned station, and use of fire protection / fighting procedures must be developed, particularly for engineering spaces. The main elements of this strategy include:

- Remote sensing of spaces - This included smoke, Carbon Monoxide (CO), heat and trends in heat, motion detection, and acoustic monitors in spaces.
- CCTV - With remote control pan/tilt mechanisms to allow crew to monitor spaces for personnel presence, smoke and fire, and equipment status.
- Ship wide alarm systems - (see enabling technologies).
- Remote fire fighting - In conjunction with remote sensing, CCTV, and ship wide alarms, remote fire fighting can be controlled from the bridge or damage control central. Capability for remote

light-off of HALON, AFFF, mist sprays, and/or CO_2 can be provided to reduce (1) response time, and (2) number of crew needed to respond.

- Flex response DC teams - This requires modifying organizational strategies to responding to damage control situations.
- Enhanced fire suppression methods - For example, mist spray systems.

None of the interviews noted any work-reducing technologies associated with DC activities such as dewatering, desmoking, or grounding. The Netherlands ship the VAN NES, however, does provide much remote control of systems vital to DC. These include systems such as ventilation, electrical, and fluid systems; these are controllable not in response to DC issues as much as to support routine plant operations. This work-reducing automation is discussed in section 3.2.7 "Engineering Strategy." Several efforts that are underway which may have extensive work-reducing benefits to IDS, include:

- advanced remote sensing of spaces via the US Navy's Reduced Staffing through Virtual Presence (RSVP) program
- the US Navy's Damage Control Automation for Reduced Manning (DC-ARM), and,
- the US Navy's firefighting philosophy in the DD 21 program for automated inerting of the atmosphere and combustibles in unmanned spaces.

3.2.2 Multiple Crews. In this strategy, each ship has more than one crew, with a corresponding reduction in the total number of ships in the fleet. Ships would be operated at a higher tempo to achieve the same number of fleet-wide underway days as there would be with a one crew per ship strategy, each ship being at-sea fewer days per year. (Whether a reduced number of ships is adequate to meet national needs, such as surge operations when a requirement exists to put as many ships to sea as is possible, is an issue outside of this report). Other elements of this strategy include the following.

- 2:1, 3:2 or other crew-to-ship ratios can be considered.
- Technical Representatives and maintenance riders may be required to support some of the more technical, high workload aspects of maintenance. Use of technical maintenance representatives aboard was a common theme among the fleets surveyed.
- Watch rotations other than three sections may be considered for this strategy. Diverse watch rotations were noted in the course of the surveys. One that may be a candidate for the surface platform of the IDS is that used by the Dutch for bridge watchstanders. They use a 7 on, 5 off, 5 on, 7 off rotation for a port/starboard watch rotation. This allows bridge watchstanders a seven-hour interval to amass continuous sleep.
- Technical support staffs may be provided for maintenance or other work normally performed ashore. Expertise can be maintained ashore and accessed via video conferencing. The types of support staffs that could be provided include: medical emergency, legal consultation, equipment diagnostics, mission planning, and logistics.
- The ashore crew may be able to support maintenance and support of ships in port, and may lead to reduction of shore personnel.

3.2.3 Risk Acceptance. Many of the fleets surveyed seemed to have a higher threshold of risk tolerance than the USCG. The most predominant risk area involved the ability to conduct multiple missions simultaneously, their manning - mission performance trade-offs have emphasized operational manning reduction. For most fleets, a system of prioritizing missions and operations is achieved such that high priority mission elements are performed first (given available manpower), then successively lower priority missions are attended to. Of course, all maritime fleets must make manning/cost/system performance trade-offs, but the tendency among those fleets interviewed seemed to afford greater emphasis to the manning/cost factors than the occurrence of infrequent or unlikely mission conditions and situations.

The main elements of this strategy include:

- Tolerate some inability to meet operational "what if's."
- Serial vs. parallel mission area accomplishment:
    - Based on assessments of threats and mission element priorities.
    - Legal / Doctrine changes may be required to institute this in the USCG.
- Advanced mission planning based on risk analysis is required.

3.2.4 Deck Strategy. Overall, there were few approaches discovered that reduce work associated with deck operations (other than the bridge). The main elements of this strategy include:

- Mooring - use of automated line tensioners to obviate the need for humans to tend mooring lines as tides rise and fall, and to support berthing and mooring operations.
- Cross training - use of engineering personnel to support low frequency or special deck operations. These operations include: line handling during berthing; helicopter deployment and recovery (using the ship's crew to tie down, fold rotors, set lanyards and stantions, etc.); and line handling (painters) for small boat deployment and recovery.
- Anti corrosion control/coatings - use of advanced coatings on high corrosion surfaces to reduce facility and structures maintenance, and to reduce (even eliminate) the need to grind, chip, and paint surfaces when underway.
- Operating procedures and processes:
    - Communications - team activities (anchoring, berthing) is facilitated by use of hand held UHF or VHF radios, obviating the need to rig or access deck sound powered phones or other communications devices.
    - Remote monitoring - use of CCTV systems to monitor deck (anchor windlass, mooring lines, various tied down components, personnel) and spaces (personnel presence, presence of hazards, smoke, fire).

No approaches were noted during the interviews that specifically addressed reduction of workload or personnel requirements for underway replenishment (fuels or dry stores), or small boat deployment, operations, and recovery. With regards to replenishment, the CGC DEPENDABLE did make use of a portable conveyor to load stores from the weather to below decks, reducing the size of that work party from six to four. For all organizations interviewed, technology and procedures for small boat deployment were found to be highly similar to those used by the USCG. The USCG Barracuda class coastal patrol boat employs a ramp stern launch system for it's single small boat. This system is reported to require only a single person (other than those being deployed on the small boat) to launch, and also a single person to aid in boat recovery. This can be compared to four to six required to launch and recover small boats using standard boats on davits.

3.2.5 Ship / Personnel Readiness Strategy. Fewer crew members aboard ship means that overall ship manning is less tolerant of personnel shortages (due to incapacitation or sailing short). Fewer crew also often means that each crew member must maintain a broader set of skills and abilities. The main elements of this strategy include:

- Extensive cross training of personnel.
- No deck/engineering/aviation barriers - This involves scenario/event based work allocations across departments. For example, engineering department personnel participating in helicopter recovery, or using mess cooks as line handlers when conducting boat operations. This requires that (1) operational scenarios be generated, (2) functions be identified, analyzed, and allocated, and (3) for main evolutions/mission segments, personnel must be assigned tasks based on availability, regardless of department or rank.
- 100% manning allowance - This means that the cutter does not leave the pier with a crew less than the manning allowance (of course, there will be exceptions, such as simply transiting from point to point for overhaul, but these situations should be expressed in manning allowance documents).
- Control of crew fatigue - Crew fatigue must be monitored and controlled. Mechanisms to monitor fatigue must be part of the ships operational procedure, as well as specifying means to reduce fatigue once it has been identified. It is also noted here that none of the fleets surveyed has imposed a mechanism to formally assess crew fatigue. In all cases, ad hoc judgements on the part of the crew and officers was relied upon to assess fatigue.
- Use of civilian crew, in part or in whole.

3.2.6 Bridge Strategy. Two main bridge themes emerged from the data, those being (1) reduction of *workload* via application of automation, or (2) reduction of *personnel* by virtue of task and procedure redesign. In the latter, work was not removed, but was simply consolidated into the responsibilities of fewer people. Higher risk tolerance was also noted in the task redesign approach, as bridge lookouts were often consolidated with helmsmen and command authority.

Essential bridge automation strategies include:

- Integrated Bridge System - These generally include radar sets, electronics charts, Global Positioning System (GPS) data feed to electronic charts, Closest Point of Approach (CPA) computation software, summary displays (helm displays, depth under keel, propulsion).
- Engineering Control - This entails direct control of main engineering functions (prop pitch, engine speed).
- Bridge Watch Station Design - Port-Starboard watchstanding (see also Multiple Crews strategy, above).
- Client CPU to Ship's Network - Allows control of auxiliary systems such as ballast control and ship to shore communications via electronic data links.
- Deadman Alarm - In the event of a one-man bridge watch, an alerting device that times control inputs (helm control or use of radar touch screen) is required. In the event that a specified interval elapses (nominally ten minutes) without some control use (including use of radar touch screen) an alarm sounds in the CO/XO quarters, the mess area, and the lounge/recreation areas.
- Ship-wide Surveillance (CCTV and monitors) - CCTV surveillance of engineering spaces and the deck (particularly anchor windlass, ship entry points, and boat handling areas).
- Bridge - Operations Rooms located together.
- Cleaning and Maintenance – Bridge facilities maintenance by shore gangs.

- Damage Control/Fire Fighting Controls Station (CO2 light-off, engine room deluge).

Other automation such as Global Maritime Distress and Safety System (GMDSS), communications devices, and autopilots common to state-of-the-art bridge designs have been omitted from the list.

3.2.7 Engineering Strategy. The engineering spaces will be unmanned a significant portion of the time when underway. Significant watch station labor is saved by using an intelligent computerized monitoring system, consisting of separate and redundant computers communicating with a number of substations and displays. The engineering watch will be maintained in an engineering control room or the bridge. High criticality alarms (alarms that if not responded to, could lead to loss of propulsion, electrical, or navigation systems) will be routed to the engineering control room and bridge. Alarms should be supplemented by decision aids.

Corrective maintenance will be reduced by provisions for a high level of redundancy in vital systems. Preventive maintenance workload will be reduced through use of a reliability based and/or a condition based maintenance philosophy. This requires the use of extensive Built-In-Test (BIT) and systems monitoring hardware. The concept for surveillance and alarm systems is:

- Alarms are prioritized to support unmanned engine room operations.
- All alarms are announced in engineering watch station.
- All alarms logged in the engineering watch station.
- All critical alarms announce in engineering control room, engine room, bridge, engineer's stateroom and ship's office.
- Unacknowledged critical alarms are also announced in the galley and captain's stateroom.

This strategy is also tied to the watchkeeping element of unmanned engineering spaces. Status monitoring and alarm systems will need to be integrated within the total ship, such that alarms (engineering and piloting/navigation) are repeated throughout the vessel. This is of particular importance at night when the engineering space will be unattended and only a few watchstanders are available on the ship. Critical engineering and piloting/navigation alarms need to be presented in the following spaces:

- CO/XO stateroom (navigation and piloting alarms, general alarms, vigilance/dead man alarm from bridge).
- Chief Engineers stateroom (engineering alarms).
- Lounges, other recreation areas (gym).
- Messing area.
- Operations room.

Only high priority alarms need to be presented in these spaces, and low priority alarms should be sounded only in the main spaces affected (engineering and bridge).

In some cases, additional elements of this strategy can include:

- Shore support for preventive maintenance (PM) - major PM can be handled by shore components who board when the ship is in port.
- Bulk of logistics support is provided by shore personnel.

- Engineering facility maintenance (elements of cleaning, painting) provided by shore personnel.

3.2.8 Modularity Strategy There were several examples of modularity of design in the fleets participating in the survey. Modularity encompasses the following two components:

Hardware. In this case, the ship can be configured to accomplish different missions depending on the payloads and hardware installed. For example, an air defense missile system (that exists as a warfare area module) can be removed from the ship and replaced with an anti-submarine warfare (ASW) module (or a research module, or a weapon module). Depending on mission need, hardware modules are removed and replaced with modules that support the mission at hand. Using this approach in the Deepwater project, a standard surface platform could similarly be configured to support different operations, such as National Security (by adding weapons and ASW hardware), drug interdiction (by adding a brig and surveillance modules), or alien migrant interdiction operations. Workload and manpower reduction occurs in hardware modularity because mission specialists are required only for the specific missions to be accomplished during a deployment.

Shore infrastructure. The modular ship concept requires that shore facilities be available for the storage, handling, and change out of ship mission modules. In addition, the shore infrastructure needs to support the personnel associated with modules that are not assigned to a ship and support any system maintenance required for modules that are in ready storage. Although not absolutely required, assigning major cutters to homeports collocated with module storing and handling facilities would be very beneficial to implementing this strategy.

3.2.9 Enabling Technologies. Enabling technologies represent ship infrastructure that (1) provide ship services that support (or are required to implement) other work-reducing strategies and (2) can directly, in and of themselves, reduce workload. For example, provision of hand held radio devices (UHF/VHF) facilitating communications for all ship activities, thereby reducing overall workload. Specific enabling technologies include:

Network and Client-Server Architectures - The major element of this enabling technology is a ship's network and advanced internal communications. Provisions for a network of computers in a client-server architecture including: bridge, main engineering, ship's office, CO's stateroom, XO's stateroom, conference room/library, and other working spaces. Both legacy and new software should be accommodated by the networked computers. The ships network represents a ship's infrastructure element that enables numerous work-reducing strategies, including systems monitoring and control, communications, area surveillance, and redundancy. The objective is to permit access to ship monitoring and control functions from many locations aboard. The main uses of the ship's network and computing system include:

- Engineering and auxiliaries status displays.
- Logistics data base maintenance and PM scheduling.
- Ship-shore communications (logistics data, completed forms such as weather observations to NOAA, operations summaries, mission plans, etc.).
- Machinery condition monitoring.
- Summary navigation displays (course, speed, etc.).
- Alarms and status monitoring.
- Administrative duties.

- Storage and presentation of training material.

Ship Surveillance Systems / Space Monitors - Ship wide monitoring entails the installation of CCTV in main spaces as well as compartment monitoring of smoke, toxic gases, and heat. The objective of this is to reduce the time spent by roving personnel checking spaces. CCTV can be used to support visual inspection of spaces on routine basis or in response to alarms. Space sensors would be incorporated in ship-wide alarm systems (network based) for presentation in various spaces (see other strategy areas).

Wireless Ship Communications - Provision of hand held UHF and VHF radios to facilitate communications.

Shore Establishment (logistics, maintenance, operations planning) - Implementation of any of the work-reducing strategies will have an effect on the requirements for support from ashore. A well planned and adaptive shore establishment will be required to reduce work, and crew, aboard the surface platform of the IDS .

3.2.10 <u>Design for Operability and Maintainability</u>. The thrust of human engineering as applied to ship design is to reduce human workload, and consequently manning levels, and to reduce the incidence and impact of human error. In the reduction of workload and manning, human engineering is focused on four specific approaches.

Automation of System Functions – Human engineering provides a process for the analysis of functions and the allocation of function performance to human or automation. The major concern here is to establish the roles of the human and automation in completing each system function, and to define the interactions between automated systems and human operators.

Elimination of Functions - Functions are offloaded from shipboard to shore, such as administrative activities and maintenance support, and training (distance learning).

Consolidation of Functions - Consideration is given to combining functions which are separated in existing systems.

Simplification of Functions - Human engineering design standards are applied to equipment design to reduce workloads and error potential. Decision aids are provided to further reduce cognitive workloads, and human engineering simulation exercises are conducted to determine the impact of design concepts on human performance. Function or task simplification requires that, for critical tasks assigned to a specific operator or maintainer, the demands that these tasks make must be reduced to the greatest extent possible. Task demands include physical, cognitive, and perceptual-motor demands. Specific techniques for simplifying tasks in terms of task demands include design approaches to reduce:

- the amount of information to be processed.
- complexity of information processing.
- the number of decisions and options to be handled.
- complexity of actions.
- needs for interactions with other operators.
- extent and complexity of communications.
- task performance accuracy required.
- special skills and knowledge required.
- level of stress associated with the performance of tasks under representative mission condition

The Naval Research Advisory Council (1981) has estimated that application of human engineering to navy systems will result in a manning reduction of at least 20%. The U.S. Army recently completed an assessment of the expected benefits of application of human systems integration (HSI) on the Comanche helicopter development program. The analysis indicated that through HSI, the Comanche would realize a cost saving over its lifetime of $3.2 billion, most of which is directly attributable to maintenance manpower reduction through maintenance simplification. HSI initiatives in the Army's Comanche program (compared to baseline comparison systems) include: a 40% reduction in engine maintenance man-hours due to a modular engine design and human engineering design approach; a drive train with 73% fewer parts; and an engine tool kit reduced from 136 to 6 tools (Anderson et al, 1998).

Several of the organizations contacted in this study had implemented human engineering processes, principles and data reducing workload. Organizations reporting that the application of human engineering in ship design was explicit included the Canadian Coast Guard, the Royal Netherlands Navy and the British Royal Navy. The DOORMAN Class of Dutch frigates, for example, has reduced total ship manning by 16% as compared with the earlier S Class. In designing these ships, the Netherlands Royal Navy had relied on the expertise of TNO Human Factors Research Institute in Söesterberg to design human machine interfaces, assess human performance using full-scale mockups, and improve ship's communications. The result was a design that not only reduced workload, manning, and human error incidence, but also expanded mission capability and is highly acceptable to the crew.

3.3 Comparison of Strategies to Assigned Crews

The various organizations surveyed have different combinations of reduced crewing strategies and mission areas as shown in Table 2. Each organization has its own national culture and demographics, and organizational training and personnel administration programs that determine how crews are assigned to ships. Detailed information on how these organizations assign their crews based upon the survey is contained in Appendix D. A "baseline" crew for each strategy for purposes of comparison is shown in Appendix E. Table 2 and Appendices D and E may be used to identify and compare crewing strategies of the various organizations. For example, an important consideration is the duration of the time at sea in adopting crewing strategies and watch schedules; this information can be obtained in Appendix D.

Table 2. Primary Mission Areas and Strategies by Participating Organization

Strategy / **Organization**	Norwegian CG	Canadian CG	Swedish DG	French Navy	Japanese CG	Dutch Navy	Commercial	British Navy	Danish CG	USN SmartShip	USCGC DEPENDABLE
Damage Control Strategy	√		√						√	√	
Multiple Crews	√		√				√		√		
Risk Acceptance	√		√			√	√		√		
Deck Strategy		√		√		√				√	
Ship / Personnel Readiness	√	√	√	√					√		√
Bridge Strategy			√	√			√	√	√	√	
Engineering Strategy		√		√	√	√	√	√		√	
Modularity									√		
Enabling Technologies	√	√	√	√		√	√	√	√	√	√
Operability/Maint design		√	√	√		√	√	√	√		
Primary Mission Areas											
Commercial Use							√				
Search and Rescue	√	√	√		√	√		√	√		√
Fisheries Inspection	√	√	√			√			√		√
National Defense/Patrol	√		√	√	√	√		√	√	√	√
Environmental Protection	√	√	√								√
Law enforcement	√	√	√			√		√	√	√	√
Ice Breaking									√		

4.0 COST ANALYSIS FINDINGS

The Life-Cycle Cost (LCC) impacts of the crew optimization strategies need to be investigated in order to make an informed cost-benefit decision regarding implementation. Where possible, data from crew optimization surveys has been used to estimate strategy implementation costs and as a basis for describing unquantifiable opportunity costs and organizational efficiency improvements associated with the crewing strategies identified during the study.

4.1 Cost Data Quality

With few exceptions, organizations surveyed were unable to accurately quantify either the costs associated with providing automation to reduce work, or the level of workload imposed on the crew after implementing the work-reducing approaches.

Sparse Data. The crewing surveys turned up good information on techniques being used in various fleets to reduce crew workload. Unfortunately, little data was available on costs associated with implementing the strategies and techniques, particularly from organizations that met the original screening requirement of 15% crew reduction and program(s) in place for greater than 3 years. A number of organizations had been operating with reduced crews for greater than 3 years, but they had largely been continuing historical operating practices, so there was no basis for cost comparison.

Wide Range for Data Obtained. The majority of cost data for strategy implementation came from the U.S. Navy's SmartShip program and the U.S. Coast Guard's PARAGON project. SmartShip and PARAGON are both trials evaluating the potential for a variety of technology implementation and procedural changes to reduce crewing requirements aboard ship. The SmartShip platform is the USS YORKTOWN (CG-48), a 10,000 ton cruiser and the PARAGON platform is the USCGC DEPENDABLE (WMEC-626), a 1000 ton cutter. The SmartShip program is ongoing. The PARAGON trial completed in January 1999.

In addition to SmartShip and Paragon, cost data from the crewing surveys was from the Swedish Coast Guard where it was estimated that high automation to reduce crewing levels would increase the acquisition cost of a ship by an estimated 20% over a traditional approach (the estimation provided by Swedish CG). The Canadian Coast Guard provided a cost worksheet for engineroom automation, and the Royal Netherlands Navy provided information on the frequency of engineroom automation maintenance and software update requirements.

Where cost data from SmartShip and PARAGON was available for similar functional automation, SmartShip costs were typically higher by more than an order of magnitude. Possible explanations include differences in the ship sizes, differences in crew size, mission area differences, and differences in accounting for program costs. For example, PARAGON cost data typically includes equipment purchase and installation cost only, while SmartShip includes equipment, installation, test and evaluation, and program management costs.

Sensitivity / Bracketing. Since little directly applicable cost data is available for the crewing strategies, three cost estimates are developed for each strategy, a nominal, pessimistic and optimistic scenario. By running three scenarios, the sensitivity of strategy rankings can be determined. The nominal case is the best estimate of the implementation costs and the crew reduction achieved through implementing a strategy. The pessimistic scenario represents a high implementation cost and low crew reduction. The optimistic scenario represents a low implementation cost and high crew reduction.

4.2 PACE Model Setup and Assumptions

As discussed above, PACE needs a baseline reference crew (in the terminology used by PACE, a "Status Quo") alternative to compare the other alternatives against. Since a nominal or baseline crew was not assumed for this study, no true reference crew exists for comparison. Therefore, a baseline reference crew was established in PACE. The reference case was set up such that PACE would not return any negative costs or crew numbers. <u>It is important to realize that the reference crew case used does not represent any cutter, either existing or planned, but only serves as a reference point to compare the crewing strategies</u>.

Further, the PACE Model setup employed the use of strategies as alternatives, meaning that by comparing each strategy to a common reference, the cost / payback performances can be ranked by relative performance against the reference. Because of this, the costs reported by PACE for each strategy are not absolute costs, but can only be used to compare the strategies to each other.

As discussed above, three cases are established for the analyses, consisting of a nominal, optimistic and pessimistic case. Each establishes a common reference, against which the eight strategies are compared. All three cases use the same reference crew alternative as baseline.

Where a new system replaces an item that would be present with a traditional crewing approach, the implementation cost represents the difference between the traditional system and the system being installed for the crew optimization strategy. For example, under Deck Strategy, the cost for advanced corrosion controls are estimated increases over using a conventional paint system.

4.3 Cost Analyses for Each Strategy

Cost analysis data for each strategy is presented below. For each, a discussion of the cost elements and personnel impacts is provided

4.3.1 <u>Damage Control Strategy</u>

Cost Elements. A number of systems are required to be installed aboard ship to reduce workload associated with damage control evolutions. Key aspects are eliminating the need for sound powered phone talkers, fire and smoke alarm systems, automating damage control closures and valves, and closed circuit television (CCTV) monitoring systems. Cost data for these systems varied tremendously between the USCG PARAGON study and USN SmartShip. Where data for similar functional equipment exists from both sources, the values are averaged for the nominal. The exception is for the Fire and Smoke (F/S) Detection and Alarm System. SmartShip doesn't break the F/S Detection and Alarm System cost out separately from other alarm and networking costs, so the nominal cost estimate has been skewed heavily towards the PARAGON value. Nominal estimates for increased system costs for these technologies per ship are:

• Advanced/Wireless Interior Communications System	$320K
• Fire and Smoke Detection and Alarm System	$500K
• Automated Closures and Valves	$200K
• CCTV System (costs included with F/S Detection and Alarms)	(see note to left)

No data was available on maintenance costs associated with these systems. The Canadian Coast Guard used an estimate of needing to upgrade or replace an engineering monitoring system after 10 years at 75% of it's original acquisition cost, which is used as the nominal case. The nominal case also assumes $5K per year of maintenance expenses over what traditional systems would require.

In addition to any possible personnel reductions, these systems offer the potential to improve response time to emergencies and reduce the amount of damage sustained in the event of fire, flooding or other damage to the ship.

While the DC strategy does afford a crew reduction, the life cycle savings associated with the crew reduction are not enough to offset the increased acquisition and system maintenance costs for the automated DC systems and equipment, at least in the nominal and pessimistic cases, using the PACE model.

Personnel Impacts - Damage Control (DC) represents an area where routine ship manning is not heavily affected, but that requires personnel be allocated to DC tasks and teams in the event of flood, fire, grounding, etc. DC therefore represents a risk area in terms of a crew's ability to respond in sufficient force and in time. The technologies applied in the area of DC are intended to enhance automated responses and remote responses to casualties such as fire. In other words, the tradeoffs are associated with reduction or tolerance of risk. With regard to *general* manning levels, there are no implications due to DC automation. Regarding operations under high readiness levels, USCG cutters already employ an approach similar to the SmartShip Flex concept, and therefore little procedural reduction of manning is afforded. However, given automation, there is the probability that the size of a Flex DC team may be reduced, or DC team members may be allocated concurrent tasks and functions when no casualty conditions occur.

An overall reduction of two crew is estimated for the nominal case.

4.3.2 Multiple Crewing Strategy

Cost Elements. Multiple crewing may allow the U.S. Coast Guard to accomplish the same cutter operations level with fewer ships. There are some possible crew efficiency improvements due to reduced fatigue, available 'off-ship' time, and because additional personnel from the off ship crew(s) could be available for facility maintenance when the ship is in port. These, however have not been counted on in the cost analysis.

The cost analyses assume that cutters are crewed with three crews for two cutters. This ratio would require that the cutters be underway 270 days per year to achieve the same operations tempo as a one crew for one cutter approach achieves with 185 days underway per year. This results in a savings of one-third of a ship for each crew compared to a one-for-one crewing strategy. Obviously, other ratios of crew to cutters are possible. This saving is significant. The PACE model shows that for a notional $250 million dollar national securing cutter with a crew of 110, the cutter acquisition cost greatly exceeds the discounted life-cycle cost of the crew.

There is a cost assumed for developing the crewing policies associated with a multi-crew strategy. For the nominal case, it is assumed policy would be developed in a six-month study staffed by six U.S. Coast Guard officers with a support team contracted at an expense of $250K.

Total cutter operations and maintenance (O&M) costs are assumed to be unchanged by this crewing strategy. Most operations and maintenance expenses are connected either directly or indirectly to operating hours and this strategy does not change the total fleet wide operating hours per year. The assumption is that maintenance costs per cutter would increase, but the number of cutters is decreased by the same factor so that the total system O&M costs remain the same.

Multi-crewing involves a number of non-quantifiable and opportunity costs. With a smaller number of hulls, the U.S. Coast Guard's capability to respond to short duration, high tempo operations is reduced. For example, in the current fleet it is theoretically possible to have twelve WHECs underway at the same time for special situations. If a multi-crewing strategy were in place at 3 crews to 2 cutters ratio, there would be a theoretical maximum of eight WHECs available. Multi-crewing also increases the operational cost of ship time lost to casualties since it is less likely that a cutter will be available to cover a hole in the patrol schedule caused by unscheduled emergency maintenance.

Personnel Impacts. There are no assumed onboard personnel reductions as a result of this strategy, however, reductions in shore support personnel may be achieved. Total crew per ship, however, increases by about 50%. Cost savings result from procuring fewer ships.

4.3.3 Risk Acceptance Strategy

Cost Elements Risk acceptance does not necessarily require any systems/technology investment, although systems discussed in Enabling Technologies and some of the other strategies can serve to mitigate increased risks associated with reduced crewing levels. The concept is to eliminate watchstanding or other workload that is associated with unlikely events that have an acceptable risk associated with them. As a hypothetical example, if crew size was driven by a notional scenario involving concurrent law enforcement boarding, helicopter operations, and a fire, the Coast Guard could decide to reduce the crew size and accept the risk. If that scenario were to occur, helicopter operations could not be conducted until one of the boarding teams was back aboard or the damage control party was secured.

The assumed implementation cost for the Risk Acceptance is an analysis/study to evaluate mission scenarios that are crew size drivers and evaluate the implications of not being able to perform selected scenarios. The nominal case cost for the Risk Acceptance study is assumed to be a one year study staffed by six U.S. Coast Guard officers with a support team contracted at an expense of $500K.

Personnel Impacts. Work avoided due to tolerance of risk is difficult to estimate. Work reduction will depend on the operational situation and the level of risk tolerated for each situation. Risks can be tolerated in terms of:

- Conduct of damage control activities and assumptions concerning extent of casualties and effectiveness of automated systems.
- Assumptions regarding reliability and availability of hardware.
- Assumptions concerning the effectiveness of the mission.
- Assumptions concerning operational intensity and the ability to conduct simultaneous operations.

- Assumptions concerning crew readiness and availability.

A crew reduction of 10 is assumed for the nominal case. However, it is impossible to estimate what reduction might be possible through careful study of watchstanding and work routine to identify functions that could be eliminated with tolerable risk to the U.S. Coast Guard.

4.3.4 Deck Strategy

Cost Elements. Equipment and systems associated with implementation of the deck strategy are automatic mooring winches, automatic anchoring equipment and advanced corrosion control systems. Automated equipment for boat handling would be an ideal fit for this strategy. However, no systems with a proven track record of greater than three years were discovered that would reduce workload beyond what is already in use in the U.S. Coast Guard (with the exception of a stern launch boat on a current USCG Coastal Patrol Craft).

The nominal cost case assumes automated mooring winches and anchoring equipment would add $100K to the cost of the ship, would add $5K per year in equipment maintenance expenses, and the deck machinery would be overhauled at a cost of $20K every 5 years. Advanced corrosion control system costs were estimated based on SmartShip. Since the USCG National Security Cutter will likely be a smaller ship than the USS YORKTOWN, the nominal first cost for advanced corrosion control systems is estimated at $100K, approximately half the reported SmartShip expense. It is assumed the coating system(s) will need to be reapplied every 7 years for the nominal case.

Personnel Impacts. For the nominal case it is assumed that the net impact of this strategy allows a crew reduction of three.

4.3.5 Ship / Personnel Readiness

Cost Elements. The Ship / Personnel Readiness strategy involves crewing cutters with a smaller number of more experienced, highly trained personnel. Costs and benefits of this strategy are not quantifiable without creating a specific application tailored to the U.S. Coast Guard. Organizations adapting this approach include the Swedish Coast Guard, Canadian Coast Guard, and the Royal Netherlands Navy (RNLN).

Personnel Impacts. The most highly developed application of this strategy found was the Swedish Coast Guard. The Type 181 offshore patrol vessel (51 meter, 900 ton) is operated with a crew of 11. Crews are assigned to stations, not to specific ships, but do tend to stay with the same ship. Watches are a one in three rotation with a mate, deck officer and engineer comprising the watch section. The only non-watchstanders in the crew are the Captain and the cook-steward. All crewmembers are officers with an average salary of approximately $65,000 per year. In addition, Swedish Coast Guard personnel typically have prior naval or maritime experience and go through over two years of training before being assigned to ships.

The Canadian Coast Guard is a civilian organization. Ship crews are typically over 50% officers.

The Royal Netherlands Navy does not assign their most junior personnel to ships. A RNLN sailor would typically have at least two years of experience in shore and training assignments before serving aboard ship.

All three organizations have some form of collective representation and pay overtime and/or allow compensatory time off for extended work hours and extended underway periods. Most major maintenance is performed through either contract or organizational shore support. The level of shore support varied among the organizations. As expected, the smallest crew (Swedish Coast Guard) relied most heavily on shore support. The RNLN performed routine maintenance with ship's crew, but utilizes shore support for major maintenance. For example, a diesel engine overhaul would not typically be performed by the RNLN ship's crew.

4.3.6 Bridge Strategy

Cost Elements. Reducing workload on the bridge is accomplished primarily by application of automation. An Integrated Bridge System with automated navigation plotting, voyage planning, and radar plotting is required to achieve the reduced level of watchstanding. In addition, a number of organizations rely on variations of a port and starboard watch rotation to reduce the total number of crew required to support bridge watches. Costs for an Integrated Bridge System are based on retrofit costs reported for a number of ship types. The nominal case assumes a first cost of $500K with a major upgrade of $375K at 10-year intervals. Annual maintenance expenses are assumed to be the same as for a traditional bridge configuration.

Personnel Impacts. Bridge automation can reduce bridge watchstanding dramatically, the extent to which is closely related to risk acceptance (see above). Reductions cited here assume moderate tolerance for risk and provision of highly automated bridge.

With a highly automated bridge, it is feasible to operate with three bridge watchstanders (command, navigation/communications and lookout). The nominal case assumes reduction from five bridge watchstanders in a one-in-three rotation, resulting in a crew reduction of six.

4.3.7 Engineering Strategy

Cost Elements. A number of systems are required to be installed aboard ship to reduce workload associated with engineering watchstanding and maintenance. Key aspects are reducing the number of watchstanders by employing remote alarm and machinery monitoring systems, automated system control, and implementing Condition Based Maintenance (CBM) and Reliability Centered Maintenance (RCM). Cost data for these systems varied widely between USN SmartShip and a Canadian Coast Guard cost comparison. The nominal first cost for an automated alarm, monitoring and control system is estimated to be $2,000K, which is slightly skewed toward the Canadian Coast Guard estimate for the system. In addition, $10K per year is estimated for maintenance of the automated system. This is based on a report from one survey participant that software upgrades and system maintenance are performed every 6 months. The nominal case cost for developing CBM / RCM procedures is assumed to be a one year study staffed by five U.S. Coast Guard officers with a support team contracted at an expense of $500K.

Personnel Impacts. Engineering automation can reduce watchstanding dramatically. The extent is closely related to risk acceptance (see above). Reductions cited here assume moderate tolerance for risk and provision of a highly automated engineering plant monitoring and control system. With a highly automated system, it is feasible to operate with two engineering watchstanders. The nominal case assumes reduction from five engineering watchstanders in a one-in-three rotation resulting in a crew reduction of nine.

4.3.8 Modularity Strategy

Cost Elements. Modularity involves construction of the ship such that systems that are not needed for every patrol are modularized, allowing them to be reconfigured for specific mission scenarios, thereby offloading those modular systems that will not be used in the mission. Costs and benefits of this strategy are not quantifiable without creating a specific application tailored to the U.S. Coast Guard. Expected benefits are (1) the ability to perform the tailored mission capabilities available for a smaller ship size, (2) the potential to create new modules in the future to meet new mission requirements, and (3) potential for crew reduction based on highly tailored mission requirements.

Costs would need to include those associated with developing the shore infrastructure to store, handle, and maintain modules that are not deployed on any particular mission.

Personnel Impacts. Immediate crew reductions are provided for those DW capabilities that are not deployed on any particular patrol. Another personnel benefit is that modules, while in ready storage ashore, can be maintained ashore, reducing the maintenance burden aboard. Specific crew makeup (and therefore, crew size and any reduction) are entirely dependant on the extent of modularity and the modules deployed on any specific mission.

4.3.9 Enabling Technologies

Cost Elements. - Enabling technologies represent ship infrastructure that (1) provide ship services that support (or are required to implement) the other work-reducing strategies and (2) can directly in and of themselves reduce workload. For example, provision for hand held or wearable radio devices (UHF/VHF) will facilitate communications for all ship activities, thereby reducing overall workload. A variety of automation technologies can be installed aboard ship that enable workload reducing policies to be implemented. Key aspects are Local Area Network and Wide Area Network installations, wireless interior communications systems that eliminate the need for phone talkers and reduce the time spent contacting people, fire and smoke alarm systems, automated damage control systems, CCTV monitoring systems, and integrated bridge, engineering and command and control systems.

Nominal estimates for increased system costs for these technologies per ship are:

• LAN/WAN Installation.	$1,000K
• Advanced/Wireless Interior Comms System.	$320K
• Integrated Bridge System.	$500K
• Automated Monitoring and Alarm Systems.	$2,000K
• Fire/Smoke Detection and Alarm System.	$500K
• Automated Closures and Valves.	$200K
• CCTV System (Costs included with F/S Detection and Alarms).	(see note to left)

No data was available on maintenance costs associated with these systems. The Canadian Coast Guard used an estimate of needing to upgrade or replace an engineering monitoring system after

10 years at 75% of it's original acquisition cost, which is used as the nominal case for this type of equipment. The nominal case also assumes $95K per year of maintenance expenses over what traditional systems would require. The nominal case for the LAN/WAN system also includes $150K every 3 years for software and hardware upgrades.

Personnel Impacts. The nominal case crew reduction is assumed to be 17, which is based on the aggregate reduction from the Damage Control, Bridge, and Engineering Strategies.

4.3.10 <u>Design for Operability and Maintainability Strategy</u>

The Naval Research Advisory Council (1981) has estimated that application of human engineering to navy systems will result in a manning reduction of at least 20%. The costs associated with implementing Design for Operability and Maintainability stem from having human factors engineers involved in the ship design process beginning during the early stages of ship design. Assuming a 3-year concept-preliminary-detail design process for the ship, this would add approximately $500K - $1,500K to the ship design costs. Those costs would be spread over the number of ships in the class to get the acquisition cost impact.

4.4 Cost Summary

Figure 2 shows potential crew reductions by strategy, but does not show costs of strategy implementation. For example, the Damage Control strategy shows a crew reduction, but the life-cycle costs of implementing and maintaining the automated systems exceed the life cycle savings of the crew reduction, as projected by PACE. Similarly, the Multi-Crewing strategy does not show any crew reduction, but has a substantial life-cycle cost savings due to the acquisition cost savings resulting from purchasing fewer ships. Estimated crew reductions are described under Personnel Impacts for each strategy in section 4.3.

The discounted net value of each strategy, as calculated by PACE, over a 30-year cutter life is shown for the nominal, optimistic and pessimistic cases in Tables 3, 4, and 5.

Positive values represent life cycle savings of the strategy. As can be seen, the value of the strategies relative to each other remains fairly constant across the three modeling cases. Costs shown are 30-year net discounted savings of the strategy per notional crew.

The Multiple Crewing Strategy shows the greatest life cycle savings. This is particularly interesting since Multiple Crewing generates all its savings in the form of lower up front acquisition costs (fewer cutters are purchased). There are several organizational and opportunity costs associated with this strategy (discussed above) that could not be included in the cost model. For example, there is value associated with the ability to respond with a greater number of ships in a crisis and there is value associated with the operational flexibility to deal with unplanned downtime that is provided with a larger number of ships. However, the potential savings are great. Comparing replacement of the 378' WHEC fleet with a hypothetical one-for-one vs. a 3:2 multi-crew strategy, 4 fewer ships need to be procured, resulting in a total acquisition cost savings of roughly $600 million to $1 billion.

The only strategy investigated that shows a negative return in the nominal case is Damage Control. This is largely because the Damage Control technologies reduce crew requirements during emergency evolutions, but do not greatly reduce routine workload aboard ship. Crewing requirements for special evolutions and short-term emergency type scenarios were beyond the scope of this study. It should be noted that Damage Control automation technology implementation may be required in order to adequately respond to emergency situations with reduced crews.

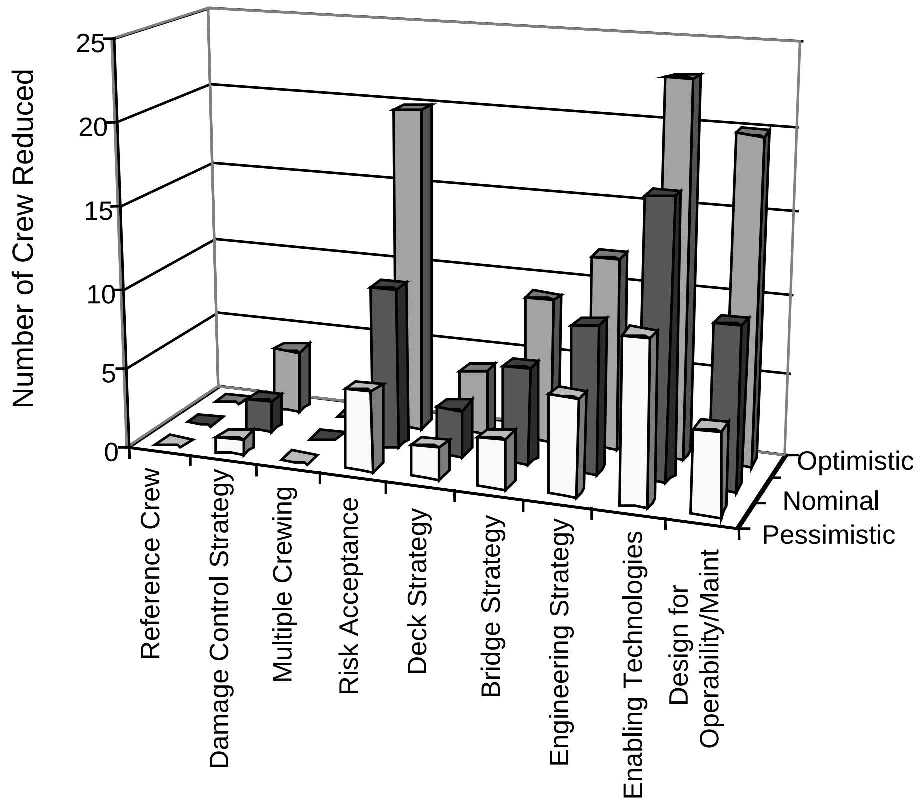

Figure 2. Potential Crew Reductions by Strategy

During review of the results, it was noted that the personnel cost figures from the PACE model seemed low. Therefore, they were compared to the personnel costs and default inflation and discount rates used in the U.S. Navy COMET model. The COMET model personnel costs, default inflation value and default discount rates produced a 30-year life-cycle cost for personnel that ranged from approximately 2.6 to 3.0 times greater than the PACE model.

This is the result of three key differences in the models: (1) COMET uses a default inflation rate of 3.0% for personnel costs, the PACE default inflation rate is less than 1%; (2) COMET uses a discount rate of 5.0%, the PACE default is 7.0%; and (3) COMET applies a much wider range of indirect expenses to personnel costs, which results in current year personnel costs that are nearly twice what is found in PACE. PACE applies a 15% default general detail to account for indirect expenses while COMET explicitly calculates indirect expenses. Of significant interest, even with the higher personnel costs from COMET, the discounted present value of a notional 106 person crew over 30 years is still less than the acquisition cost of a notional $250 million cutter.

To investigate the impact of higher personnel costs on the strategies, the nominal cases were loaded in a spreadsheet and the total 30-year discounted personnel costs multiplied by a factor of 2.8, the average difference between COMET and PACE costs. The result is shown in Table 6.

Table 3. Nominal Strategy Values

Strategy	Nominal Discounted Present Value of Strategy per Crew
Reference crew	
Multiple Crew	$82,436,719
Risk Acceptance	$6,101,641
Design for Operability/Maintainability	$5,225,703
Enabling Technologies	$2,978,653
Bridge	$2,721,287
Engineering	$2,169,123
Deck	$742,395
Damage Control	($737,669)

Table 4. Optimistic Strategy Values

Strategy	Optimistic Discounted Present Value of Strategy per Crew
Reference crew	
Multiple Crew	$101,123,736
Risk Acceptance	$13,605,076
Design for Operability/Maintainability	$13,170,123
Enabling Technologies	$11,822,037
Bridge	$6,569,714
Engineering	$6,003,440
Deck	$1,647,577
Damage Control	$1,254,106

Table 5. Pessimistic Strategy Values	
Strategy	**Pessimistic Discounted Present Value of Strategy per Crew**
Reference crew	
Multiple Crew	$49,857,445
Risk Acceptance	$3,434,004
Design for Operability/Maintainability	$1,574,711
Bridge	$103,448
Deck	($331,620)
Engineering	($3,595,219)
Damage Control	($7,350,875)
Enabling Technologies	($8,506,698)

The Multiple Crewing Strategy still shows the greatest life-cycle cost savings, but by a narrower margin than that with the unmodified PACE costs. Also, as the cost of personnel increased, the relative ranking of high investment alternatives to reduce crew, such as Enabling Technologies, improves.

In summary, all the strategies investigated show good potential to reduce crewing and generally show positive benefits to cutter or ship life-cycle costs through those crew reductions.

Table 6. Nominal Strategy Values with Estimated COMET Personnel Costs	
Strategy	**Nominal Discounted Present Value of Strategy per Crew (using estimated USN COMET personnel costs)**
Reference crew	N/A
Multiple Crew	$82,381,646
Enabling Technologies	$19,800,971
Risk Acceptance	$15,496,612
Design for Operability/Maintainability	$14,730,820
Engineering	$10,401,852
Bridge	$8,999,274
Deck	$2,989,536
Damage Control	$2,287,928

5.0 RESEARCH REQUIREMENTS AND RECOMMENDATIONS

All the strategies investigated show good potential to reduce crewing and generally show positive benefits to cutter or ship life-cycle costs through those crew reductions. The strategies, however, need to be carefully assessed for applicability to the USCG missions and operating environments. The workload and manning strategies of other fleets evolved based on the specifics and peculiarities of their missions, operating environments, economics, and political and social values. It is almost certain that some strategies, while highly effective in other environments, will be simply and completely unsatisfactory for use by the USCG. Given this, several areas have been identified where additional research is needed to help determine the usefulness and applicability of each strategy to the USCG and the SP-IDS. These are summarized below:

Mission/Function analysis. Mission profiles should be developed to support development of a total ship-manning concept. Mission profiles with resulting crew tasks will then provide the baseline for verifying and validating manning and workload concepts. Part of mission analysis should include a top-down requirements analysis including a man-machine allocation effort. Mission, function, and allocation information will be needed to develop notional crewing concepts, support crew level validations, and support operational testing. Topics that should be addressed as a result of the Mission/Function Analysis include:

- Risk Analysis. The history of other fleets workload and crew reduction efforts were looked at in this study, but we did not look at the tradeoff processes and assumptions that led to reduced workload designs. Specific risks to USCG missions need to be assessed for each candidate strategy addressed in this report.
- Validation of workload, sustainability, and fatigue levels. None of the fleets surveyed were able to accurately assess crew workload, accumulation of fatigue, or sustainability of high paced operations for their ships and crew. Simulation or other analysis methods should be considered to verify that applying work-reducing techniques and any resulting crew reductions do not result in unacceptable levels of crew fatigue.
- Identify crew size drivers. Identify those mission elements and characteristics that induce high work requirements.
- Develop notional multi-crew plan. Analyze USCG mission areas and high surge operations history to evaluate the feasibility of operating with a multi-crew concept for various cutter classes. This could include analyzing modifications to USCG away from homeport policies.
- Training Requirements Analysis. Apply analysis portions of the Instructions Systems Development (ISD) process to identify training requirements, training plans, and verification and validations procedures.

Operations Analysis. Strategies need to be compared to USCG missions and operations. Mission/operations analysis need to be performed for the following:

- Deck operations. There was little uncovered to reduce work associated with a high driver function, that of deploying and recovering small boats. There is a need to examine further means to automated deck operations and to provide advanced deck features.
- Air operations. Little was identified to reduce work associated with air operations. Policy and procedures changes were noted in the area of cross training personnel to support launch and recovery, but nothing in the area of maintenance and conduct of ongoing air operations.

- Shore infrastructure. Implications of reduced workload and crewing for shore establishments need to be fully analyzed and the shore capability required to support implementation of strategies must be better understood. Failing to do so might dramatically increase risk and mission reliability during deployments.

Long term training and force maintenance. Cross training of a crew may severely impact current training pipeline and on-board training. A training requirement analysis is needed for any strategy selected for development and implementation. Impacts on long term force structures and sustainability must also be investigated.

Notional crew for National Security Cutter. Strategies were developed within specific functional categories since a total crewing concept is not at hand. Strategies need to be examined within a total ship/crew concept of operations.

Human engineering design requirements and guidelines. A significant amount of human work aboard ships can be traced to poor design of human interfaces, accesses, and maintenance design. Means should be instituted such that human engineering design efforts are directed at human performance, safety, and workload reduction.

Crew cost validation. Model crew costs in other military cost models, such as COMET, for comparison to PACE results and sensitivity of strategy payback to personnel costs.

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